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Behaviour of different types of fibre reinforced concrete without admixture

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Abstract

In this paper the behaviour of the normal concrete and concrete with different types of fibre (steel, macro-polypropylene and micro-polypropylene fibres) have been studied; in terms of the compressive strength, split tensile strength, density, and the workability for concrete grade 30 without admixture. Varied fibre content to determine the optimum strength with 1%, 2%, and 4% by the volume of cement, cubes specimens of size 100mm×100mm×100mm to test the compressive strength were cured for the period of 7, 14 and 28 days before crushing, and cylinder specimens with 100mm diameter and 200mm length were cured for 28 days before breaking. The results show that there are some limitations of adding fibres to the mix; however the use of fibres has shown a significant change on the behaviour of the concrete without admixture. In total, 66 specimens including the normal concrete were cast and tested in comparison. The test also results show that the use of steel, macro-fibre, and micro-polypropylene change the failure types to ductile failures, thus overcoming the brittleness problem of the concrete, and improves the split tensile strength.

Keywords: *fibre, steel, macro-polypropylene, micro-polypropylene, optimum strength, Compressive strength, split tensile strength, Aspect Ratio.*

1. Introduction

Portland cement is commonly utilized in the construction sector, the concrete that is manufactured from this cement has some features. It is strong in compression; however, it is brittle in tension [1]. Generally, it was found that the addition of fibres to the concrete mixtures made significant changes to the brittle tension reaction of the concrete. The efficiency of the fibre depends on factors such as the volume content, the length of the fibre, the aspect ratio, and the tensile strength of the fibre [2].

Moreover, even the addition of small quantities of fibre produces a substantial increase in the strength of the concrete once cracked in the development stage [3]. In addition, substantial achievements have been made towards crack control, with a reduction in the cracks' width and spacing. The reduction in crack width and the increased resistance to corrosion developed the long-term serviceability of fibre concrete by stopping the penetration of chemicals and water, which may have adverse effects [4]. Previous research has investigated the effect on the properties of concrete with the addition of polypropylene and steel fibres which have widely different elastic moduli [5]. The strength properties of hybrid nylon-steel and polypropylene-steel fibre-reinforced high strength concrete were also investigated and compared. The experimental results show that the compressive strength and splitting tensile strengths and modulus of rupture (MOR) properties of the nylon-steel fibre concrete improved by 3.2, 8.3 and 10.2%, respectively, over those of the polypropylene-steel fibre concrete [6].

The strength and fire resistance properties of glass fibre concrete were also investigated. It was found that reinforcing with glass fibre contributes immensely to enhancing the compressive strength of concrete with an increase equal to 1.78 times that of normal concrete [7]. The durability of fibre reinforced concrete of marine structures was investigated. Polypropylene triangular fibres were used for the reinforcement. It was found that this improved the durability of the concrete as well as the compressive strength to a dosage up to 0.3%, but then started decreasing [8]. Fibre-reinforced concrete in precast applications and the role of fibres in improving mechanical properties and durability were reviewed [9].

An experimental investigation was carried out on steel fibre reinforced concrete beams strengthened with fibre reinforced polymer laminates. The resulting beams were found to have higher load carrying capacity with a 48% increase in the ultimate load and a 63% decrease in deflection at ultimate stage [10]. Concrete reinforced with 0.1 vol% of different synthetic fibres of steel, polypropylene, glass, and carbon were investigated. It was observed that the type of fibre used had a huge impact on the workability of the concrete. Only the steel fibres were found to enhance the density of concrete. It was also found that the given fibre dosage enhances the early compressive strength of concrete but reduces the 28 days compressive strength. Steel fibres increase the tensile strength more than any other fibre used during the investigation. It was noticed that addition of fibres in concrete largely improves the failure pattern of the concrete subjected to compressive loads [11].

Currently, civil engineering installations have structural and durability requirements of their own, each structure has its own intended purpose, and thus to meet this target, the modification in the conventional cement concrete has become necessary. Therefore, this investigation examines the behaviour of various types of fibre and compares it to the normal concrete, and highlights the properties for each type of fibres. In this paper, different sets of concrete specimen were prepared to study the behaviour of steel fibre, micro-synthetic polypropylene fibre, and macro-synthetic polypropylene fibre reinforced concrete in comparison with conventional concrete without admixture (see Fig. 1).

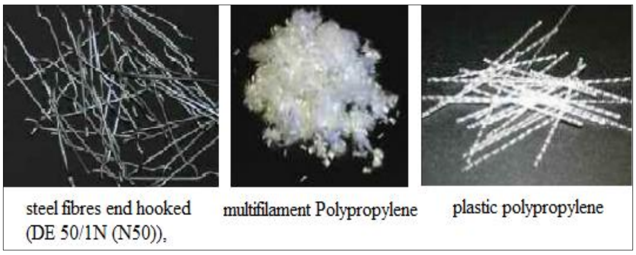

Figure 1: The different types of fibre that used in this investigation

2. METHODOLOGY

2.1 Preparation of the samples

The paper focuses on the usage of Steel, Micro-Synthetic Polypropylene, and Macro-Synthetic Polypropylene fibres reinforced concrete. In this investigation the steel fibre is stiff and strong, whilst the polypropylene fibre is more ductile and flexible. Samples have been made to find out the compressive strength, and split tensile strength for each type of fibres. The fibres properties that wereused in this experimental investigation are illustrated in Table 1.

Table 1: Properties of the fibres used

Material	**Fibre Type**	**Length**	**Diameter**	**Aspect Ratio**
Steel Fibre	DE 50/1N	50mm	1mm	50
Macro-Fibre	Plastic Polypropylene	50mm	1mm	50
Micro-Fibre	multifilament Polypropylene	6mm	18μm	333.3

In total 66 samples were tested. Table 2 gives the distribution of the tests that were carried out and the number of samples tested for each case.

Table 2: Distribution of the tests that were carried out and the number of samples tested for each case

	Normal Concrete	Concrete with Steel Fibres	Concrete with Plastic Fibres	Concrete with PP Fibres
Compressive Strength after 7 days	3 Samples	9 samples, 3 samples for each percentage of fibre content (1%, 2% and 4%)	9 samples, 3 samples for each percentage of fibre content (1%, 2% and 4%)	9 samples, 3 samples for each percentage of fibre content (1%,2% and 4%)
Compressive Strength after 14 days	3 Samples	3 Samples	3 Samples	3 Samples
Compressive Strength after 28 days	3 Samples	3 Samples	3 Samples	3 Samples
Tensile Strength	3 Samples	3 Samples	3 Samples	3 Samples

2.2 Materials and Mix Proportion

2.2.1 Materials

A. Cement: Ordinary Portland Cement Grade 52.5 was available in this investigation, which has a bulk density of 1200 Kg/m^3, and a specific gravity of 3.15. Moreover this cement had a recorded strength of 58.5 MPa after 28 days.

B. Aggregates: The coarse aggregate that have been used were uncrushed gravel, and the maximum size was 10 mm. The river sand was used as fine aggregate with a particles size was less than 3 mm, and the sand specific gravity was 2.6.

C. Water: Tap water has been used to mix the ingredients of concrete

D. Fibres: All the fibres that were used in this investigation supplied by MAPEI Company [12].

- Steel Fibers: The fibres used were Steel Fiber DE 50/1N. The fibres were supplied by MAPEI by the name DE 50/1N. In the present investigation the fibres have a 50 mm (± 10 %) length and 1,0mm (± 10 %) diameter. The steel fibers have a high tensile strength of 1100 MPa (± 15 %) and aspect ratio (L/D) of 50.
- Macro-Polypropylene Fibre: The fibres used were Polypropylene Fibre. The fibres were supplied by MAPEI by the name plastic fibre M50. In the present investigation the fibres have a 50 mm (± 10 %) length and (1,28/0,81) mm (± 10 %) fiber Width/ Thickness. The plastic fibers have a tensile strength of 250 N/mm^2.
- Micro-Polypropylene Fibre: The fibres used were Polypropylene Fibre. The fibres were supplied by MAPEI by the name PP-fiber M6. In the present investigation the fibres have a 6 ± 1 mm length and 18 ± 3 µm diameter. The plastic fibers have a tensile strength 300 N/mm^2 and 0,91 g/cm^3 density

2.1.2 Mix Proportion

The concrete mix design was prepared based on the technical properties of the materials used and the required properties in the hardened concrete. Table 3 below illustrates the mix design that used for the normal concrete. It is worth noting the high volume cement content of 592.1 kg. This is a bit on the higher side of the limit of 550 kg according to BS:8007, but the calculations were based on the graphs of the DOE (British) mix method. The ratio of fine aggregate and coarse aggregate is 0.67 which is again a bit on the higher side, but not out of proportion with similar values used by other researchers. For instance Muhit et. al. [13] use a similar ratio for their mixes.

Table 3: Mix quantities for 1 m^3

Kg / m^3	**Cement**	**Water**	**Fine Aggregate**	**Coarse Aggregate**
1 m^3	592.1 kg	225 kg	691.2 kg	1036.7 kg

The volume fraction of the fibre has been taken as a percentage of the volume of the cement; in this study the concrete samples have been prepared with fibre ratios 1%, 2% and 4% by volume of the cement to find the optimum strength for each type of fibres.

3. RESULTS AND DISCUSSION

3.1 Identification of Optimum Amount of Different fibres:

To make a comparison between steel fibre, macro-polypropylene fibre and micro-polypropylene fibre reinforced concre, the normal concrete was taken as the benchmark specimen; it gave 46 MPa in the compressive strength after 7 days.

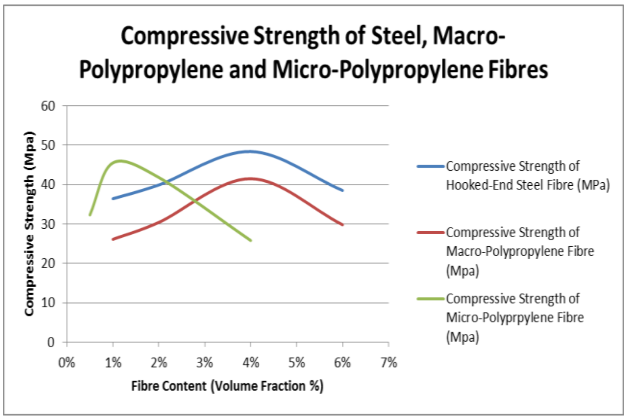

Figure 2: Density of different types of fibres with different fibre content

As illustrated in Fig.2 above, the optimum compressive strength of the steel fibres, and the macro-polypropylene fibres were found to be 4%. While the optimum strength of the micro-polypropylene fibres were 1%.

3.2 The Density:

The average density of the normal concrete cubes was 2.39 MPa. As shown in the Fig.3, the density of the cubes that have a steel fibre increases with the increase of the percentage of the fibre content, while the density of the polypropylene cubes with both types of fibres has decreased with the increase of the volume fraction of the fibre.

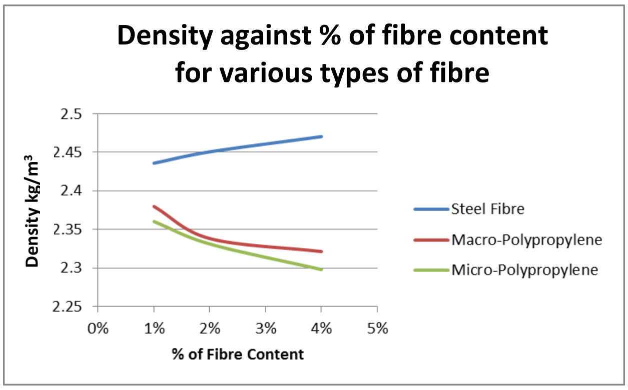

Figure 3: The Optimum Strength of Each Types of Fibre after 7 Days

The highest density among them was for the cubes that have steel fibres, and the reason is due to the density of the steel fibre which is greater than the constituent materials of the normal concrete. In case of polypropylene fibres, the decrease in the density occurs because of the reduction of the weight of the mixture that replaced by fibres.

3.3 Slump Test:

Table 4 indicates the results of the slump for the normal concrete and maximum compressive strength of different types of fibre: steel fibre, macro-polypropylene and micro-polypropylene with 4%, 4% and 1% fibre ratio respectively. It has been observed that the polypropylene fibres play a significant role in the concrete workability. With high volume fraction of the macro-polypropylene fibres which have a long length and with small fibre content of the micro-polypropylene fibres which have a short length, both types decrease the workability of the concrete largely. However, the reduction of the slump of the steel fibres comparing to the polypropylene fibres was slight, and still within the slump design mix range. It is worth noting that for the normal concrete, the slump of 93 obtained is similar to that obtained by Muhit et al. [13] for the same water to cement ratio of 0.38.

Table 4: The slump results for the normal concrete and the maximum strength for different types of fibre

Concrete	**Slump (mm)**
Normal Concrete	93
Steel Fibre (4%)	70
Macro-Polypropylene (4%)	20
Micro-Polypropylene (1%0	20

Steel fibres affect the workability of the fresh concrete, while the polypropylene fibres reduce the value of the slump significantly. However, the overcoming of this problem could be through the use of the admixture.

The use of fibres results in an increase of surface area and contributes to the apparent slump loss. Also, the type of fibre, configuration of fibre, quantity and length of fibre are all parameters that contribute to both the workability and slump of the resulting mix. Previous research [14] has shown that synthetic fibre can reduce slump by up to three inches (i.e. up to about 75 mm). The reduction seen in this research (from 93 to 20) falls within the reduction range (93-20 =73mm).

3.4 Compressive Strength Tests:

Cube specimens of size 100mm×100mm×100mm were cured for the periods of 7, 14 and 28 days before crushing.

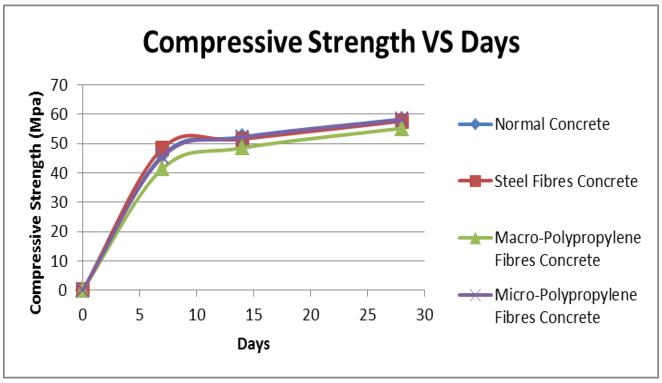

Figure 4: The Compressive strengths of the concrete with and without fibres at 7, 14 and 28 days

Initially, the compressive strength is directly proportional with the age of the concrete. As shown in Fig.4 the compressive strength of the micro-fibres mix after 28 days has reached the highest strength observed in the lab, followed by the steel fibres mix, then the macro-fibres mix, which has reached the lowest strength. However, all the mixes with fibres have not exceeded the normal concrete compressive strength after 28 days.
The compression strength of the normal concrete mix and the concrete mix with fibres has shown very similar values, which means that the compressive strength was slightly affected by the fibres addition.

3.5 Split Tensile Tests:

Cylinders specimens with 100mm diameter and 200mm length were cured for 28 days before breaking. Table 5 shows the results from the split tensile test for all specimens.

Table 5: Tensile strength after 28 days of the concrete with and without fibres

Mixture	**Tensile Strength Load (KN)**	**Tensile Strength (MPa)**
Normal Concrete	107.30	3.42
Steel Fibres Concrete	212.95	6.78
Macro-Polypropylene Fibres Concrete	176.76	5.63
Micro-Polypropylene Fibres Concrete	116.27	3.70

The tensile strength results for the normal concrete came extremely low as expected, because the concrete as known is brittle in tension, ductile in compression.

As shown in table 5 the tensile strength of the normal concrete mix (bunch mark mix) was 3.42 MPa, the micro-polypropylene fibres mix showed a very close tensile strength to the original normal mix, which was 3.70 MPa. While both of the steel and the macro-polypropylene fibres mixes showed an increment in the tensile strength capacity significantly, the macro-polypropylene fibres mix gave approximately 1.5 times the tensile strength that was observed from the normal concrete mix with a difference of 2.21 MPa, while the steel fibres mix gave almost twice the tensile strength with increased tensile capacity of 6.78 MPa.

Despite the fact that the micro-polypropylene didn't show a significant improvement in the tensile strength, the addition of the micro-polypropylene, the macro-polypropylene, or the steel fibres can overcome the brittleness problem of the concrete.

3.6 Tensile in Relation to Compressive Strength:

The tensile strength in relation to compressive strength of the normal concrete was 5.86% lower, and the percentage of the micro-polypropylene fibres was slightly higher than this value with 6.36%, while both of the macro- polypropylene fibres and the steel fibres reached almost twice the ratio of the normal concrete (Table 6).

Table 6: Compressive strength in relation to the tensile strength

Concrete	**Compressive Strength (MPa)**	**Tensile Strength (MPa)**	**Tensile Strength in Relation to Compressive Strength (%)**
Normal Concrete	58.4	3.42	5.86
Steel Fibres Concrete	57.7	6.78	11.75
Macro-Polypropylene Fibres Concrete	55.3	5.63	10.18
Micro-Polypropylene Fibres Concrete	58.2	3.70	6.36

3.7 Tensile strength and workability in Relation to Aspect Ratio:

The aspect ratio of the fibres is the ratio of the lengths over the diameter. Table 7 illustrates the tensile strength, the workability and the aspect ratio of different types of fibre.

Table 7: The Tensile strength, the slump and the aspect ratio of different types of fibre

Concrete	Tensile Strength (MPa)	Aspect Ratio	Slump
Steel Fibres Concrete	6.78	50	70
Macro-Polypropylene Fibres Concrete	5.63	54	20
Micro-Polypropylene Fibres Concrete	3.70	54.5	20

As shown in the table above, the highest aspect ratio was for the micro-polypropylene fibres, which has obtained the lowest splitting tensile strength with 3.70 MPa, followed by the macro-polypropylene fibres which reached a 5.63 MPa tensile strength, and the lowest aspect ratio was for the steel fibres with the highest tensile strength at 6.78 MPa. Therefore, the relationship between the aspect ratio and the tensile strength is inverse correlation.

It can be noticed that the aspect ratio of the macro-fibres and the micro-fibres is very similar (54 and 54.5 respectively), resulting also and in the same slump value. While the steel fibres which have the lowest aspect ratio reached the highest slump and the best workability (see Fig.5).

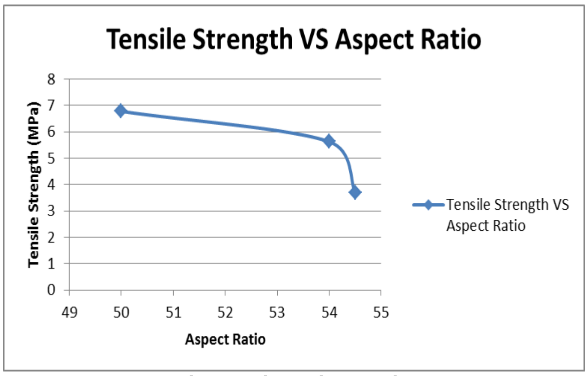

Figure 5: Tensile Strength in Relation to the Aspect Ratio

One of the main issues of fibre reinforced concrete is the workability. Usually, fibres usage decreases the slump, and several factors play a role in the workability of concrete, such as the volume fraction of the paste, the fibre content, water content and the aspect ratio of the fibre. However, a reduction in the slump does not necessarily mean that the mixture becomes harder to compact. Fibres that have a high surface area can make the mixtures to some extent drier.

There is a strong link between the slump and the fibre content; which means that the workability of concrete is highly influenced by the fibre content. Therefore, to show the effect of the fibre; the normal concrete has been taken as a bench mark. As shown in Fig.6, the normal concrete slump was within the range that it was designed for, observed at 93 mm, and the concrete was homogenous and the mixture was moisturized enough.

The Slump of the Normal Concrete

Figure 6: Slump of the normal concrete

With the 1% fibre content of micro-fibres, the slump decreased compared to the normal concrete (used as the benchmark) with 20mm.With the increase of the micro-fibre dosage to more than 2%, the slump dropped till the slump reached zero, and as is observed in figure 7, the mix appeared to be sticky and relatively dry after taking the slump cone off. This has drawn attention to the amount of water that been sucked by the fibres. In Addition, the aggregate particles were segregated and not surrounded well by the mix. As can be seen, increasing the fibre dosage to more than 4% leads to collapse (Fig.7).

1% of the Micro-Polypropylene Fibres | More than 2% of the Micro-Polypropylene Fibres | More than 4% of the Micro-Polypropylene Fibres

Figure 7: The Slump with different percentage of the Micro-Polypropylene Fibres

For the macro-polypropylene fibres as shown in the Fig.8, there weren't any significant differences between the high and the low fibre content. The macro-polypropylene fibre was easier to consolidate, and that was due to the lower surface area per weight.
A high dosage of the fibres needed to be added to the mixture before the slump significantly decreases. High dosage with 4% fibre content of the macro-polypropylene fibres gave the same slump as the micro-fibres with very low dosage (with 20mm). Moreover, the macro-fibres with high fibre contents in the mixture seemed as fully wet as the low fibre content; the macro-polypropylene fibres did not dry up the mixture as much as the micro-polypropylene fibres did. Furthermore, adding more than 4% of the macro-fibres did not lead to collapse, only the slump became very close to zero.

2% of the Macro-Polypropylene Fibres | 4% of the Macro-Polypropylene Fibres | More than 4% of the Macro-Polypropylene Fibres

Figure 8: The Slump with different Percentage of the Macro-Polypropylene Fibres

As shown in the figure below, it has been observed that the slump of the steel fibres reinforced concrete reduced by increasing the fibre content. However, the reduction in the slump was not as significant as the other types of fibre compared to the normal concrete and was within the range of the mix design. The steel fibres have shown the best workability compared to the other types of fibre (Fig.9).

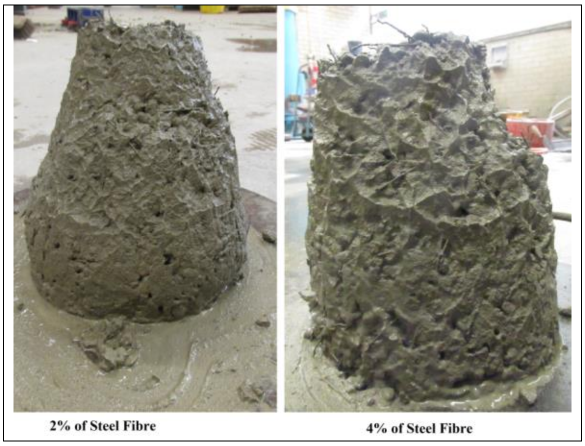

Figure 9: The Slump with different Percentage of the Steel Fibres

In summary, the highest aspect ratio led to the lowest tensile strength and workability, and vice versa (Fig.10). Moreover, after the aspect ratio of 50 the tensile strength and the workability went on decreasing. Thus, the best impact strength and workability could be realized an aspect ratio equal to 50.

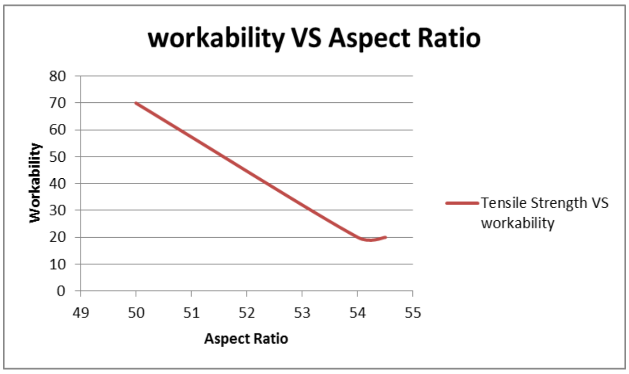

Figure 10: Workability in Relation to the Aspect Ratio

3.8 Comparison between different types of fibre:

This investigation tested three types of fibres (steel, micro-polypropylene, and macro-polypropylene), and this section provide some attempts to classify each type of fibres. This is not intended that all fibre types of those classifications will follow the trends seen; because these are observations. The Normal concrete was taken as a benchmark of these observations for comparison purposes (Table 8).

Table 8: Comparison between different types of fibre

Property	Steel Fibres	Macro-Polypropylene Fibres	Micro-Polypropylene Fibres
Slump decrease	Moderate decrease	Major decrease	Major decrease
Fibre dosage increase	Density increase	Density decrease	Density decrease
Drying of mixture	Minimal drying	Moderate drying	Major drying
28 days compression strength	Slight decrease	Slight decrease	Slight decrease
28 days tensile strength	Major increase	Major increase	Slight increase
brittle decrease	Major decrease	Major decrease	Moderate decrease

4. CONCLUSIONS

- The optimum compressive strength results of steel, macro-polypropylene and micro-polypropylene fibres were found to be 4%, 4%, and 1% respectively.
- The addition of the steel, macro-fibre, and micro-polypropylene does not provide a significant improvement in the compressive strength after 28 days. Compared to the normal concrete; the compressive strength values of the concrete with fibres has dropped slightly.
- The failure types significantly changes after adding the fibre to the mix with more ductile failures.
- A direct correlation between the density and the fibre dosage was found for the steel fibres (increase the steel fibre dosage increases the density). While an inverse relationship was found for the micro and the macro polypropylene fibres (increase the percentage of macro or the micro polypropylene fibres content decreases the density).
- The addition of the micro or the macro polypropylene fibres in the mixture creates problems in workability, which decreases the slump significantly.
- The tensile strength value of the steel fibres increased by almost twice the tensile strength of the normal concrete, while the macro-polypropylene fibres increased by almost 1.5 times, while the micro-polypropylene fibres did show a very close value to the normal concrete.
- The addition of the macro-polypropylene, the micro-polypropylene, or the steel fibres can overcome the brittleness problem of the concrete.
- The aspect ratio of 50 is the most suitable to reach the highest tensile strength and workability.

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